HARVARD INSTITUTE FOR TROPICAL BIOLOGY AND MEDICINE

A Report on the Sugar Cane Mosaic Situation in February, 1924 at Soledad, Cuba

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A Report on the Sugar Cane Mosaic Situation in February, 1924 at Soledad, Cuba

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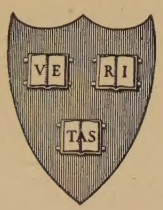

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INTRODUCTORY NOTE

In this new series, entitled "Studies from the Harvard Institute of Tropical Biology and Medicine," it is planned to publish such reports as may, from time to time, be offered as a result of the activities of the various contacts which Harvard University has established with the Tropics, in the broad fields of Biology and Medicine.

To be sure no announcement can be made at just this moment of the complete organization of this Institute which is planned to combine and coördinate the various Harvard activities having relation to tropical problems.

The first paper to appear is a report by Professors East and Weston, on the Mosaic Disease of Sugar Cane. This is a preliminary account of the disease as it appeared in Cuba at the time when they made a visit to the Island as the guests of Edwin F. Atkins, Esq. Mr. Atkins has been for very many years not only a planter of sugar, but he has founded and endowed a botanical garden and biological laboratory which is now part of the Harvard Institute. This report was intended primarily to inform Mr. Atkins of the probable danger from the mosaic disease in Cuba; and as it would seem to be of great interest to all sugar planters, and as it summarizes the best contributions of those who have studied the disease, I believe that its publication will be of real interest and value. It is not, however, to be considered a final report, for Professor Weston has visited Cuba since this was written and plans to return there in the near future for further work.

T. B.

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A REPORT ON THE SUGAR CANE MOSAIC SITUATION IN FEBRUARY, 1924 AT SOLEDAD, CUBA

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INTRODUCTION

In preparing the following report on sugar cane mosaic, the writers have drawn upon the important published works bearing upon the condition as it exists in sugar cane and in other plants, upon experience with mosaic infections in other species, in particular Solanums and grasses, and upon a personal investigation made during the month of February 1924 at Soledad — an estate situated near Cienfuegos, Cuba.

The primary aim in the report has been to present a résumé of our conception of the cane mosaic situation as it exists on this estate, and to deal particularly with the aspects of the situation that are of importance to Soledad. The paper was written as a personal and quite informal report to Mr. Edwin F. Atkins, but at his request it is now being published in the hope that some of the suggestions contained may be of use to growers of cane at other centrals. Naturally it would be impossible in such a short period of first hand investigation to push beyond the trail of facts already blazed by others. We have considered the available facts carefully, however, and believe that the conclusions which are here set down are warranted by the evidence, even though they may be somewhat different from those drawn by other investigators. In addition, certain points of view have been suggested regarding the sugar cane mosaic situation in general which we hope may prove helpful in future researches. These suggestions are submitted merely as plausible hypotheses which are verifiable by experiment but are as yet untested.

The conclusions and recommendations, upon which we are in close agreement, are presented in the next few paragraphs. The foundation upon which they rest is considered somewhat more fully later.

CONCLUSIONS

1. The mosaic of sugar cane occurring at Soledad is the same infectious disease widely known as sugar cane mosaic in other parts of the world. It has the essential characteristics of that whole group of diseases called mosaic which are found on a great variety of plants. The most notable of these characteristics are first, the mottling of the leaves in which irregular, patternless areas of light, gray green replace the usual dark green color; and second, the infectious quality of the juice from the young, growing leaves so mottled. Plants the leaves of which are marked with hereditary chlorophyll abnormalities may be distinguished from plants with mosaic by the fact that their juice is non-infectious, and their leaf markings form a more definite, regular pattern. Plants with malnutrition chloroses show a more uniform blanching or yellowing, and tend to occur in restricted patches in the field.

2. Sugar cane mosaic in general is widely distributed. It has been recorded in all of the chief cane growing countries, including Java, India, the Philippines, the Hawaiian Islands, the United States, Porto Rico, South America, and Cuba, and possibly even occurs unrecorded wherever cane is grown. In Cuba it has been reported from one or more localities in each province, and every estate from which reliable information is available reports its presence. It seems probable from its history elsewhere that cane mosaic is generally distributed although unreported in all parts of the Island; and interprovince quarantine measures are no longer of value.

3. As a general rule, the distribution of diseases newly introduced into a country is characterized by ever increasing areas that spread out more or less obviously from the original point or points of introduction. Furthermore, a species of plant invaded by a newly introduced parasite usually shows very little tolerance to it, and gains relative immunity only after lethal selection has operated through many generations. In view of the widespread distribution of mosaic in Cuba and

the resistance to it shown by Crystalina cane, which of course is propagated wholly by cuttings, there is strong reason to believe that the disease has been disseminated throughout the Island for many years.

4. The infectious nature of sugar cane mosaic at Soledad has been the subject of interested discussion since the presence of mosaic was first noticed there in 1916. Although at Soledad no experimental inoculation has been successfully achieved, the infectious nature of the "virus" in cane juice has been shown satisfactorily in various, widely separated, cane growing countries by Brandes, Kunkel, Ledeboer, and others. Such positive evidence is held to be conclusive despite the failure of several workers to obtain like results.

5. Although at Soledad, no positive experimental results have been obtained to show the transmission of mosaic by *Aphis maidis*, nevertheless the success in other parts of the world of Brandes, Ledeboer, Bruner, Kunkel, and Chardon and Veve, in transmitting the disease under carefully controlled conditions to plants which were healthy at the time of inoculation, by means of *Aphis maidis* as an intermediary, suggests this species of insect as an agent in natural dissemination in Soledad as well.

6. *Aphis maidis* has not been proved to be the active agent which brings about secondary infection on a large scale in the field; but one should not overlook the circumstantial evidence that this may be the case.

7. While the sources of infection may at times be the wild grasses growing near the cane fields, the most important source presumably is diseased cane. There is no evidence that mosaic is transmitted through flower seed from infected plants, but there is abundant evidence that diseased seed pieces (cuttings) usually give rise to mosaic shoots. Seed pieces from diseased plants do not always give rise to visibly diseased shoots; but the correlation is very high. It is probable that if the conditions most favorable for development of the disease could be

reproduced at will, then cuttings from diseased canes planted under such conditions would invariably give rise to obviously diseased plants. Whether the converse of this proposition is true or not depends upon whether canes showing no symptoms of the disease may function as carriers — a possibility for which there is some evidence.

8. Since there is convincing evidence that a living parasite belonging to the filterable viruses is the effective cause of mosaic, obviously unfavorable environmental conditions cannot produce mosaic; but given the presence of the infective agent, environmental conditions do affect the development of the visible symptoms of the disease. We cannot say definitely, however, that any particular condition or combination of conditions are favorable or unfavorable to this disease, although in general it appears that conditions rather favorable to plant growth are also favorable to the development of the disease. It is possible, though not wholly probable, that this result obtains because those conditions at certain seasons of the year which favor cane growth are also favorable to the growth or time of attack of disseminating agents.

At Soledad in February infection was found in cane of all ages. We found high percentages on extremely vigorous cane about 17 months old; low percentages on young cane 5 months old, and on old cane 5 years old and older. We found mosaic on cane in every type of soil — some high percentages on bottom lands and low percentages on plants suffering from drouth or from lack of soil fertility.

Various types of soil were tested for acidity and found to be neutral or slightly alkaline, hence one cannot say whether or not the reaction of the soil influences the development of mosaic.

9. Field records, Mr. Grey's experiments, and cases observed at Soledad seem to show that many, indeed at times a majority, of the shoots from an infected plant may throw off all symptoms of the disease after the stool has given definite evidence of infection. The conditions necessary for apparent

recovery from mosaic are unknown; but it is our conviction that once a plant is visibly infected with mosaic, it by no means need invariably remain so for all time. How great a part apparent recovery plays in the amount of infection over large areas in the field, remains to be determined; but it is of interest to note that only recently Kunkel reports a case in which in a test plot, the instances of recovery outnumbered those of secondary infection.

10. No sign of the so-called secondary symptoms of mosaic — internode shortening and canker — which have been reported from Porto Rico were seen at Soledad in February. Stem cankers were observed associated with root rot, but not with mosaic. In fact, since cankers of the stalks have not been shown always to be a necessary result of mosaic in either Cuba or Hawaii, we believe it unwise to accept conclusions of Porto Rican investigators that they occur inevitably.

11. We saw no evidence that the mosaic disease at Soledad is cutting down either the tonnage of cane per acre, the yield of juice, the sugar content, or the purity. The yield of sugar per acre on fields where there is a high percentage of mosaic is as large as from fields where infection is negligible. On the other hand, we do not hold that it has been proved that infection occurring at an early age and long continued, has no adverse effect on the cane. The records from Hawaii and from the United States appear to show that the disease does materially reduce the tonnage of cane per acre in varieties of cane that are very susceptible.

12. As compared with susceptible species of plants like tobacco which can be infected with mosaic under practically all circumstances, sugar cane is a resistant plant. In this quality it resembles some of the other species of Solanaceae which can be infected with the virus of tobacco mosaic only with difficulty and which will apparently recover from the disease under favorable conditions. The varieties of cane which we have examined, both the commercial ones and those originated by Mr. R. M. Grey, the plant propagator at the Soledad garden — some 50

of which have been tested sufficiently at Soledad to justify conclusions — exhibit hereditary differences in this regard. Probably none is wholly immune, neither does any show a very high degree of susceptibility. Among the more resistant varieties are Harv. 1306, 1304, and 1196. Mr. Grey says that on Uba — a cane generally accepted as immune — he has found mosaic, although this was not seen by the writers; and although several of his own seedlings have thus far shown no infection, he believes that no variety is immune. Indeed total or absolute immunity of seedlings in any one variety of sugar cane is hardly to be expected when one considers what widely different genera and species of the grass family are subject to mosaic.

13. We found no evidence that mosaic is showing any marked tendency towards increase either in amount or in destructiveness in the present plantings at Soledad.

14. Whether mosaic is likely to become more destructive in the future than it has been in the past on the estate is a very difficult question, for prediction is always hazardous; yet there is circumstantial evidence upon which to base a rough generalization, and this evidence points to the probability that mosaic will continue indefinitely to behave as it does at present.

Conceivably a combination of conditions especially favorable to the development of mosaic at Soledad might arise at any time which would bring about a destructive epidemic. In the whole history of plant pathology, however, it has been noticeable that introduced diseases which become devastatingly destructive, such as grapevine mildew and the chestnut blight, usually develop with increasing virulence in a relatively short time after their introduction.

If sugar cane mosaic had been introduced into Cuba recently, it might possibly be expected to act in this manner, but if it has been present here even for so short a time as ten years, it seems probable that in some season during that period conditions would have been sufficiently favorable to have brought out all of the virulence of which it is capable. All of the evi-

dence seems to point to the probability that the disease has been long established here in Soledad, at least; and that through long continued association the commonly grown variety of cane and the mosaic have reached a state of balance with resulting toleration on the part of the cane and relative harmlessness on the part of the mosaic.

15. The differences of opinion regarding the destructiveness of sugar cane mosaic appear to have arisen through an unfortunate tendency to draw conclusions regarding all cane varieties from experiments on susceptible types. Even though the tonnage and sugar content of susceptible varieties are markedly lowered by the action of mosaic, it does not follow that varieties as tolerant as Crystalina are so greatly injured. These hereditary differences in cane varieties ought to be taken into account in all reports on the subject.

RECOMMENDATIONS FOR SOLEDAD

As far as we can learn from general statistics of production and from our observations in the field at Soledad, cane mosaic does not appear to have been desperately destructive in Cuba up to the present. Indeed the sudden drop in yield in Porto Rico, just after the close of the World War, that was attributed to mosaic may have been the result of a number of additional causes. Such a cause may have been, as Mr. E. F. Atkins has already suggested, the planting under the pressure of enormously high prices for sugar, of lands unsuited to cane culture. Nevertheless, it seems wise to be prepared at Soledad for such eventualities as a possible extraordinary combination of weather conditions which might enormously increase the spread of mosaic, or a possible building up of its virulence to a much more destructive point. Caution is wise as a mere matter of insurance even though there seems to be no occasion for immediate alarm. Caution is particularly needed in the case of sugar cane, because cane in common with all such species propagated by cuttings shows a lower degree of variability than do seed-propagated species, and consequently has not the in-

dividual differences in the field that enables a proportion of the plants to survive a sweeping epidemic.

For these reasons we recommend that only seed apparently free from disease be used for propagation. The easiest practical way to obtain such seed is a method which has been used with success in the United States for other crops — a method which has been suggested already for use at Soledad by Mr. L. F. Hughes. It consists of setting aside a seed plot in every colonia where the cane is given the best agricultural treatment possible, and is kept disease-free by constant rogueing (pulling up diseased plants). Seed should be taken only from these plots unless there should be a shortage. In the latter case, the propagation field should not be abandoned, rather it should be tended still more carefully to prepare for the next year's seed.

In addition, we recommend that the edges of the fields and the driveways be kept free from weeds and wild grasses which may be harboring mosaic, and from which it may be transmitted by insects to the nearby cane.

Finally, we wish to recommend most heartily that continued support be given the excellent work on cane varieties of Mr. R. M. Grey. Mr. Grey's love for plant breeding combined with his skill is a great asset for Soledad. It is possible that some of the seedlings that he has already produced would surpass Crystalina in both tonnage and sugar if given adequate trial. But even if no such happy result were probable, the continued production and testing of seedling canes is well worth the cost. There is always the possibility that some new and serious disease may be introduced which would devastate the fields of Crystalina cane even as the bud rot of coconuts has already ruined that industry in Cuba. In such an event, the main hope of the sugar industry in Cuba would lie in obtaining resistant varieties of cane which had been developed as a result of crosses either on the Island itself at such places as the Soledad garden, or outside in such famous centers as Java, Hawaii, and Barbadoes.

RECOMMENDATIONS FOR FUTURE INVESTIGATIONS

There has been a tendency to regard the "mosaic" problem as one belonging wholly to the domain of plant pathology. This is unfortunate. Progress in working out the etiology of mosaic disease has been very slow, and it is conceivable that many years may yet pass before this phase of the matter is cleared up in a thoroughly satisfactory manner. In the meantime, data very valuable to the grower can be obtained by other methods of attack. We recommend, therefore, that the following suggestions be presented to the cane growers as worthy of their attention.

A. Field Investigations

No data have been published from which one is justified in drawing definite quantitative conclusions regarding the effect of mosaic, either upon yield or sugar content of Crystalina cane. The few records published are usually comparisons between yield of canes which were infected and canes which were free from disease at the time of harvest. In these few cases there was no significant difference. It is obvious, however, that yield comparisons between diseased and disease-free canes judged solely at harvest time do not answer the question most important to the grower, viz.: Does long continued infection affect the cane adversely? One might assume, for example, that plants arising from infected seed pieces may be seriously stunted, while canes originally healthy and infected late in the season would be but slightly affected. Such comparisons of tonnage, made at the end of the growing season between recently infected cane and cane still healthy would show no significant difference.

Accurate work to determine this point in the case of Crystalina cane will take time, but we believe it to be supremely important from the practical standpoint. Fields of not less than two acres or more than five acres each should be set apart under as different conditions as possible. A trained observer should keep a record of the life history of each individual plant,

together with a record of all factors such as moisture and temperature which may have a possible bearing on the case. The plants should be followed individually from planting to cutting and through subsequent ratoon crops so that there will be an accurate record over a period of years to determine the time, persistence, and spread of infection and its relation to tonnage. In no other way will it be possible to gain a precise, quantitative knowledge of the extent to which mosaic affects the vegetative growth and storage of sugar for Crystalina cane at Soledad.

B. Histological Studies

It would seem desirable to make an extended microscopical study of the chlorophyll bearing cells in normal and in infected plants. Such studies might be expected to throw light upon two important phases of the problem.

Little is known of the effect of the disease upon the chloroplasts. They should be studied carefully, therefore, from the first appearance of infection, through the period when symptoms are most pronounced, up to the time when (in certain plants) there is apparent recovery. The results obtained would supplement the agronomical experiments just recommended, and would go far toward showing whether the disease lowers the efficiency of the cane as a sugar storing mechanism.

It is also possible that the microscope might reveal whether the disease can be carried by cane which does not show surface symptoms. It is not without the bounds of possibility that apparently healthy plants of Crystalina cane (or types similarly susceptible) may carry the virus in a more or less non-virulent form; and that through microscopic study of the chloroplasts, tests could be found by which one could pick out disease carriers (if such exist) from canes that are actually healthy.

C. Physiological Studies

Several lines of physiological investigation are full of promise. We venture to suggest two which appear to have a bearing on the problem. Recently Willstaetter has found that

normal chlorophyll can be separated into two constituents by proper chemical means, and only last summer Eyster discovered that in two varieties of corn which he had isolated, — the one characterized by a bluish green color, and the other by a light, grey green color, — a different one of the two chlorophylls had been lost in each type. Now since in cane plants infected with mosaic, the green color never disappears entirely but merely changes from dark to a very light green as if only a portion of the chlorophyll mechanism had been affected, it may be that one of Willstaetter's two chlorophylls has not been affected. Should this supposition prove to be correct, as could be shown by a simple chemical examination, a study of the life history of Eyster's two corn varieties ought to show to what extent each chlorophyll is necessary in plant metabolism.

Another suggestive line of research is that of determining the effect of light upon cane growth. Lights of varying intensity, varying duration, and of different wave lengths should be tried. It has been said to be axiomatic that any cause cutting down chlorophyll formation, as is the case when a plant is infected with mosaic, must be disadvantageous. Such a statement is not necessarily an axiom; in fact there is some evidence against it. No plants flourish more luxuriantly in tropical gardens than the variegated varieties of crotons, coleus, dracenas, and others sufficiently numerous to need no record here. Is it not conceivable, therefore, that possibly there may be an excess of chloroplast activity under tropical conditions, and that a cause which acts to cut down the manufacture of chlorophyll might not necessarily check growth?

D. Studies of Mosaic Transmission

A fourth phase of the sugar cane mosaic situation that is greatly in need of further investigation is the problem of the transmission of mosaic. Obviously a knowledge of the way in which mosaic spreads from plant to plant under field conditions is of immediate practical importance to the cane grower. Fortunately also it is one of the less baffling phases of the mosaic problem, and one in which definite practical results can be ob-

tained with certainty. It is, therefore, especially worthy of investigation.

From the work that has been done by those who have studied and observed sugar cane mosaic, the following points already have been established: — Mosaic is transmitted chiefly in cuttings, it is transmitted in some cases through the agency of certain insects, and it may be transmitted artificially by hypodermic injection of juice, but it is not transmitted by true seeds.

There is need of much further knowledge of the problem. The greatest need concerns the part played by insects in carrying and spreading the sugar cane mosaic in Cuba itself. What insects carry the mosaic in Cuba? When, where, and how abundantly do they occur? What is their detailed life history? What factors of disease, climate, and of such agricultural practices as clean cultivation or trash burning limit their activities? All of these questions are of immediate practical importance.

There is need also for a more thorough investigation of the part played by maize, sorghum, and other grasses both cultivated and wild in harboring and transmitting mosaic through the agency of insects under field conditions in Cuba. Brandes has found that the mosaic of sugar cane, maize, sorghum, and a number of wild grasses is apparently the same thing, and may be transmitted from one to another of these hosts. To just what extent this is a factor in Cuba, and what grasses are involved, is of immediate importance.

Furthermore, there is great need for a thorough study of the environmental circumstances which favor or oppose the *transmission* of mosaic by these various means. To determine whether the condition of the plants concerned, or the external environmental conditions of moisture, wind, and sunlight influence the slowness or rapidity of the spread of mosaic is also very necessary.

Finally, and this seems to us very important, investigation should be made to determine whether mosaic can persist, dormant and unnoticed, in cuttings and plants apparently healthy, ready to reappear later in new stalks or in resulting offspring

when conditions are more favorable for its active development. In our field observations of sugar cane mosaic there are some indications that this may occur; and in the case of mosaic of tobacco and potato, Allard and other investigators have shown in their experiments that these mosaics, at least, may in some instances remain dormant and latent in plant stems and tubers. If a sugar cane plant infected with mosaic may give rise to stalks and to new plants (from cuttings) that are apparently healthy but in reality are carrying dormant mosaic, this would go far towards explaining much that seems contradictory in the behavior of plants in the field; and it is very important to the understanding of mosaic that this point should be settled.

An alternate interpretation of some of these puzzling points is that cane plants may gain a temporary immunity after an experience with mosaic similar to that a human being attains after recovering from a virulent typhoid infection. Such an immunity in the case of cane might last for varying lengths of time, part of a season, one or more seasons, or one or more asexual generations. Sooner or later, however, if one may draw analogies from animal pathology, disease resistance will probably become low, and the plant again become subject to infection.

The first of these interpretations postulates a decline in virulence of an infecting agent which persists in the plant, and the bringing about of active symptoms of disease at any time by the proper combination of favorable circumstances; the second interpretation postulates a change in resistance to infection by reactions taking place in the host plants. The truth or falsity of these hypotheses ought to be determined in properly planned experiments.

THE DIFFERENT TYPES OF CHLOROSIS

1. Chlorotic Conditions in Plants

A few facts are noted here regarding the different chlorotic conditions existing in plants, both because there is a tendency among the field men to confuse with sugar cane mosaic various types of chlorosis due to unrelated causes, and because the interference with the normal chloroplastic activity that is caused by mosaic is not proved to be necessarily injurious to the plant.

Generally speaking, there are two groups of coloring matters in plants: First, the series of water-soluble pigments known collectively as anthocyans that produce the combinations of reds and blues found usually in flowers and fruits; and second, a series of yellow and green pigments only slightly soluble in water which are formed by small bodies known as chromoplasts lying outside the nucleus of the cell. When, for any reason, these chromoplasts fail to perform their normal function in building up pigments, the plants thus affected are said to be chlorotic or suffering from chlorosis.

In the leaves of most flowering plants four plastid pigments are commonly found. These pigments form two pairs of pigments — the members of each pair being closely related. One pair consists of yellow pigments, carotin and xanthophyll — the latter thought to be an oxidation product of the former. The other pair comprises chlorophyll A and chlorophyll B, of uncertain constitution, but separable from each other by their solubilities.

Carotin and xanthophyll do not appear to be essential in plant metabolism. At least one, and perhaps both of the chlorophylls, which can be formed only in the presence of light, are necessary in some quantity if the plant is to function properly.

The plastids which build up these pigments may be interfered with by abnormal environmental conditions, by hereditary variations, and by the action of parasites. Our present interest in the third group attaches only to the agents which cause mosaic disease.

2. Malnutrition Chloroses

Various soil deficiencies and extraordinary moisture conditions cause the appearance of chlorosis in plants. Deficiency in iron, calcium, potassium, phosphorus, or nitrogen will result in marked chlorotic effects on most of our common field crops. In some cases, for example in Indian corn, both a deficiency and an excess of moisture will cause similar results. Malnutrition chloroses are easily distinguished from other chloroses, however, by the rather uniform blanching or yellowing which the plants undergo and by the way they tend to be grouped together in the field — the conditions which cause the difficulty usually affecting areas of a considerable extent.

We saw several examples of malnutrition chlorosis in the cane fields at Soledad. Some of the plants appeared to be suffering from insufficient moisture, others from an excess of lime. In each case, the whole plant had a characteristic "starved" appearance which could be distinguished with certainty from mosaic. In fact the experience of one of us with several thousand experimental "pots" of corn, wheat, and oats, where malnutrition chloroses were produced and controlled artificially, and where the ensuing results were always similar, leads us to believe that such conditions can never very closely simulate the appearance of mosaic.

3. Hereditary Chloroses

Hereditary chloroses of many types exist. Any combination of the four plastid pigments may be affected. In Indian corn between fifteen and twenty of these variations have been isolated and their hereditary nature carefully determined. Types similar to those of Indian corn exist also in sugar cane. We found three different kinds in the field, and four kinds among Mr. Grey's seedlings. Many others probably could be found if an adequate search were made. In appearance they are similar to those described in Indian corn, hence conclusions drawn from the investigations made on the better known crop may help us with our sugar cane.

Plates 4–8 are examples of hereditary variegation as found in corn. With the exception of the types shown in Plate 9 where the inherited abnormality may be merely a susceptibility to an omnipresent organism, there is a distinct and definite pattern. Familiarity easily enables one to distinguish between these variations and the markings of mosaic although the differences are difficult to describe. The infectiousness of the juice is the critical determining characteristic of mosaic, but nevertheless there is a sufficient difference in the leaf markings to assure the certain recognition of mosaic plants in the field.

Since now it is quite generally appreciated that mosaic is an infectious disease and not an hereditary chlorosis, there is no need to discuss the matter here; but we have included the plates in order to aid those who are unfamiliar with the various types of chlorosis in distinguishing between them and mosaic.

There is another important matter, upon which these plates throw some light. Practically all of the hereditary variations in Indian corn shown here have reduced the chloroplastic activity of the varieties in which they are found in a far greater proportion than does the mosaic infection in the cane plant. In spite of this fact, most of these varieties of corn go through their life histories in a manner apparently normal and produce good crops even in the relatively weak light of the north temperate zone. In fact Dr. G. N. Collins of the United States Department of Agriculture recently told one of us that in some of his experiments these variegated types yielded better than the normal varieties from which they arose.

These results do not prove by analogy, of course, that there may be no loss from sugar cane mosaic through the adverse effect on the chlorophyll-forming activity of the cane plant; but they do seem to indicate that in varieties of cane sufficiently tolerant so that mosaic is unable to destroy totally the chlorophyll-forming mechanism, there may be an excess of carbon-assimilating power sufficient to prevent the disease under tropical conditions of long hours of bright sunlight from cutting down the sugar storing capacity.

4. Infectious Chloroses

Of the infectious chloroses, the mosaics are the only ones that interest us here, since there is no doubt in our minds that the infection seen at Soledad is true sugar cane mosaic. This disease, then, is one of that general group of plant diseases for which the term mosaic commonly is used — a group which shows certain remarkable similarities to the filterable, ultramicroscopic virus diseases of human beings and animals. All of these alike are somewhat baffling compared to other diseases in that the exact nature of the causal organisms is not known; but all in common have the characteristic that the infective principle — the virus — which causes the disease, behaves as if it harbored living organisms.

(a) *The Nature of Plant Mosaics in General*

Though mosaic diseases of plants long have been noticed by those concerned with the crops that harbor them, only within the last thirty years have they been subjected to careful investigation. At first, no great progress was made towards understanding or controlling them, because investigators were handicapped by accepting the erroneous theory that the mosaic condition was a bud sport similar to the yellow-patterned mutations occurring in crotons, grasses, or other plants. Later as the infectious nature of mosaic diseases became more and more apparent, it was thought that they might be caused by auto-catalytic enzymes, by bacteria, or by protozoa.

During the course of many years of investigation, however, none of these theories was found tenable, and investigators now quite generally accept the fact that mosaic diseases are true diseases caused by infectious, filterable, viruses which act like organisms of ultramicroscopic size. Although these causal organisms cannot be seen by our present microscopes, and have not yet been grown artificially in laboratory cultures, none the less the mosaic situation is by no means as vague as one might suppose. Investigation based on this understanding of the nature of mosaic has explained in great measure how these dis-

eases affect the host plants, by what means they are spread from plant to plant, and how they can be controlled.

In general the mosaic diseases produce on the leaves and other chlorophyll-bearing parts of the hosts a mottling which lacks any regular pattern, but consists of pale green, more or less elongated areas scatteringly distributed through the normal dark green tissue. In addition, mosaic on some families of plants causes the leaves to become crumpled or curled, the tissue of the stem may be broken down, and the whole plant may be stunted or malformed. Juice taken from such mosaic plants under proper conditions is infective, and will cause the same effects to develop in healthy plants into which it has been inoculated. Such juice behaves, then, as if it carried infective organisms even though it has been passed through fine-pored filters which hold back the most minute bacteria known. In addition to this evidence, the infective power of such filtered virus is destroyed by heat, and by germicides, yet it persists unharmed even though weakened in such extreme dilutions as one part to ten thousand.

The transmission of infection to healthy plants by means of mosaic virus has been well established. In some mosaics, transmission occurs very readily by the simplest and most obvious means — tobacco mosaic, for example, being transmitted by merely rubbing healthy leaves with the fingers after rubbing leaves that show mosaic. In all mosaics the infection may be transmitted from mosaic stock to healthy scion or bud in grafting or budding, and may be transferred to newly developing plants by mosaic cuttings, rootstocks, or runners. In most mosaics, infection from one plant to another does not occur through flower seed; but in the mosaic of the bean family — the Leguminosae — it may.

In all of the mosaic diseases, certain of the sucking insects which infest the host plants have been found to play a very important part in the transmission of the disease either as mere carriers or as intermediate hosts. In the case of the mosaic of potato, various European investigators as well as Orton, Schulz, Folsom, and others in America, have shown clearly

that aphids are responsible for transmitting the disease from plant to plant. In the case of mosaic diseases of lettuce, bean, and cabbage, similar insect transmission has been found by the various pathologists who have been working on these diseases. In the case of spinach mosaic, Carsner has demonstrated that not only do aphids transmit the disease from plant to plant, but they pass on this infection to their parthenogenetic offspring so that these, even in the fourth generation from the parent which fed on the mosaic plant, still are able to infect healthy spinach with the disease.

Furthermore, in the case of mosaic of the melon family, — Cucurbitaceae, — Doolittle has shown that the disease is spread during the growing season not only by the melon aphis, but also by the common cucumber beetles. It persists through the winter, however, not in these insects but in the perrennial wild cucumber.

Indeed in practically all the mosaic diseases, insect transmission is now recognized as a factor of enormous importance. That this should be so seems quite logical when one realizes that the infective power of many mosaic viruses is decreased or even destroyed by drying or oxidation, but is protected from both of these misfortunes when carried in the mouth parts or bodies of the living insects. It is significant that in such of the mosaic diseases as those that are less easily transmitted artificially, successful inoculation has been secured by pressing out the diseased juice under a protective layer of neutral oil, and squirting it into the bud of the healthy host with a glass hypodermic syringe — a technique that is a close approximation of the method of insect transmission.

Within the last year, Elmer has developed a method of inoculation with infective juice crushed out in acetone, and in this way has succeeded in transmitting the mosaics of the potato, bean, and melon families from one family to another as if, indeed, these mosaics were fundamentally the very same disease. Although his work was carried out very carefully, his results are so remarkable, and of such tremendous importance in our conception of the control of mosaic diseases in general

that they demand verification before we apply them to other mosaics in other families.

With regard to the group of mosaic diseases in general, then, the following facts have been proved by numerous careful experiments.

1. Mosaic diseases are infectious.
2. They are caused by organisms too small to be seen by the use of the present microscopical methods.
3. The limits of size of these organisms, however, have been demonstrated by Duggar who, using a graduated series of filters, was able to determine the precise point at which the virus was unable to pass through. The interstices of the filters were measured by means of colloid particles of known size.
4. Individuals and species of plants vary hereditarily in their susceptibility to mosaics.
5. Mosaic diseases affect very disastrously certain susceptible species, but on other more tolerant ones appear to have slight adverse effect.
6. In certain species the virus of mosaic may persist in individual plants which show no visible symptoms of the disease. The juice of such infected individuals may produce visible symptoms on susceptible plants after inoculation.
7. The virus of mosaics is transmitted by insects.

(b) *The Nature of the Mosaic of Sugar Cane*

If we look into the history of sugar cane mosaic, we find that the investigation of this disease and the knowledge concerning it have shown much the same trend as in the case of other plant mosaics. Sugar cane mosaic was first recognized in Java more than thirty years ago, and since then has attracted an ever increasing amount of attention from sugar growers, plant pathologists, and others directly concerned with cane culture. At first no great progress in the investigation of the disease was made; because of the acceptance of the erroneous theory that mosaic was an inherited mutation or bud sport, and hence not infectious. Gradually, however, as cane mosaic with increasing insistence demanded the attention of investigators

in various important sugar producing centers of the world, the fact began to be more and more appreciated that sugar cane mosaic, like other mosaics, was an infectious disease.

Repeated experiments, however, showed that cane mosaic is by no means as readily and simply spread as such an easily transmissible mosaic as that of tobacco, for example. Transmission of cane mosaic was not accomplished by contact or even by forcible rubbing together of healthy and infected leaves, nor could the virus resist drying or exposure to the air sufficiently to cause infection when smeared on the surface of healthy leaves, or in the developing buds. Moreover, the transplanting of bits of infected tissue into healthy plants gave no infection, and flower seed from diseased parents gave healthy offspring. Yet transmission of mosaic to plant cane in cuttings of mosaic seed pieces was found to occur with great regularity, and under field conditions spread of the disease from mosaic to healthy stools quite generally was observed.

Following what had been found in other mosaics, suspicion very naturally fell upon insects as the carriers of secondary mosaic infection under natural conditions. Brandes, in a series of experiments under carefully controlled conditions was successful in transmitting mosaic to healthy cane by means of the insect *Aphis maidis*. Kunkel in Hawaii, Ledeboer in Java, Chardon and Veve in Porto Rico, and Bruner in Cuba, corroborated Brandes' results by similar successful transmission with *Aphis maidis*. Moreover, two other insects were found to transmit grass mosaic — one, the corn leaf hopper(*Peregrinus maidis*) transmitting it from corn to corn; the other, a plant louse, *Carolinia sp.*, from wild grasses to cane. Further experiments by Brandes under laboratory conditions demonstrated also that *Aphis maidis* could transmit mosaic from sugar cane to corn, sorghum, pearl millet, crab grass, bull grass, *Chaetochloa magna*, *Brachiaria platyphylla*, and *Miscanthus sinensis*, as well as to cane.

Further work in the field by Kunkel and by Chardon and Veve showed that *Aphis maidis* lives preferably on wild grasses, but frequently migrates to nearby cane when the grasses are

cut or weeded out, with a subsequent outbreak of mosaic infection in the cane. In an attempt to approximate the favorable conditions offered by *Aphis maidis* for the protection, transmission, and subsequent inoculation of the cane mosaic virus by its mouth parts, Brandes developed a careful technique of crushing out the mosaic juice in a special press under neutral oil, and injecting it by means of a glass hypodermic into the young growing tissue of healthy plants. As a result he accomplished the successful artificial transmission of sugar cane mosaic under most exacting conditions, thus furnishing positive evidence which is not at all vitiated by the failure of other less careful experimenters to secure like results.

THE MOSAIC SITUATION AT SOLEDAD

1. Distribution of Mosaic

Mosaic is present throughout the Soledad colonias. We found it present in fields at Soledad, Limones, Rosario, Josepha, Guabairo, Caledonia, and La Vega. Mr. Hughes, Mr. Leonard, and others have seen it in other colonias as well. It seems safe to assume that no part of the estate is entirely free from the disease.

These facts seem to us to have the following significance:

Because of the wide distribution of mosaic at Soledad, because of the history of the many different fields and plantings in which it occurs, because mosaic is not transmitted by contact and the suspected insect disseminators are apparently absent from cane at certain seasons, and because of the indication of long association between Crystalina cane and mosaic at Soledad as shown by its comparatively harmless effect, we seem justified in assuming that mosaic has by no means been introduced or spread recently on this estate, but rather is of long standing and has been established there for many years.

While studying this phase of the mosaic problem at Central Soledad, the suggestion was made that Central San Agustin, because it was situated in quite a different region — near Caibarien on the north coast of Santa Clara — and comprised ex-

tensive areas in land newly planted to cane, might present a contrasting comparison. A brief survey of that central, however, showed the following situation.

Mosaic is wide spread at San Agustin also. We found it in fields near the mill, in the Administration cane at Tierra Colorada, in the cane both on old and on newly cleared land north of the track, and in fodder patches south of the track at Dominguez (K 20), near Kilometer 31 in a fodder patch north of the track, at Itabo in a large acreage, in fields at Caridad (K 45), the newly cleared colonia of Adrian Delgado, and on the recent 250 acre plantings of the colonia of Jose Delgado. Mr. Caldwell has seen it also in other parts of the estate. It is probable, therefore, that mosaic is present to some extent in all parts of San Agustin.

From the point of view of distribution the Itabo district is of especial interest. There corn, tobacco, small fruits, and cattle have been the chief interests in the past, and only during the last year at the instigation of Mr. Caldwell have extensive cane plantings been made. For these plantings no seed cane was brought in, the seed being taken from small patches of fodder cane that had been grown near the houses for many years. Both the original patches and the fields planted from them showed varying amounts of mosaic. It seems much more probable, therefore, that the mosaic had been long established in the fodder patches, and came from them in seed pieces to the new plantings, than that it came to the old and the new plantings as a recent spread by means of wild grasses or maize.

2. Quantity of Mosaic

On the several colonias at Soledad, the percentage of mosaic varies greatly. By careful examination of from two hundred to five thousand plants in representative fields, we found a variation from less than one tenth of one per cent in some localities to as much as eighty-four per cent in others. Wide differences in quantity were found not only in various colonias but also in different fields and plantings of the same colonia, and in a few cases even in different parts of the same field.

Until more exact information as to the source of seed and other factors affecting the amount of mosaic is available, it is impossible to make any very significant interpretation of the different amounts of mosaic as noted in a single month for any specific locality at Soledad.

One point, however, stands out as an interesting fact. On the whole, considering the fields seen at Soledad in February, the most mosaic was found on cane planted last spring (eight to ten months old) and on cane planted the previous fall (fourteen to sixteen months old); while the least amount was found on cane which was very young (planted in the fall of 1923) or on very old ratoon cane. No information was obtained to show whether these differences should be attributed to the source of seed or other factors associated with the two plantings in which the mosaic appeared so heavily.

In addition to the variation in amount of mosaic seen under commercial field conditions in Crystalina cane, similar differences in quantity were noted for the many cane hybrids that are grown on an experimental scale at Limones and back of the vivienda at Soledad. It would not be justifiable to attach much significance to differences in amount of mosaic which we found in these hybrids during so short a period of observation and under the conditions of one season. Mr. Grey's observations, however, extending over several years indicates that while no variety is absolutely immune to mosaic, there are some which throughout their history have shown consistently so small an amount of mosaic as to indicate a high degree of resistance (notably Harv. 1196, 1304, and 1306). In view of the fact that sugar cane mosaic occurs not only on cane but also on such quite unrelated genera of grasses as maize, sorghum, foxtail, and crab-grass (to which we now should add elephant grass — *Pennisetum purpureum* — on which at La Vega mosaic was found for the first time) it is unlikely that any mere variety of cane itself would prove to be entirely immune. Even though not absolutely immune, however, Mr. Grey's hybrids show such varying degrees of susceptibility to mosaic as to justify further investigation. Moreover, from the point of

view of insurance against a possible crippling of the cane industry by some future epidemic of a devastatingly destructive character, a supply of hybrid seedlings such as have been developed in the garden by Mr. Grey is of great potential importance; because in the case of cane, resistance to disease is found not in specimens of the same individual variety resulting from propagation by cuttings, but in the distinct varieties with quite different hereditary characters which result from sexual crosses.

3. Relation of Mosaic to External Conditions

It seems established beyond question by means of the careful work of Lyon, Kunkel, Brandes, and others, that sugar cane mosaic is infectious in character and behaves in general as do other plant diseases called mosaics. It is not, therefore, the direct result of such conditions as the physical or chemical character of the soil, the presence or absence of fertilizers of various kinds, the amount or distribution of moisture, the action of high or low temperature, or of light and shade. Neither is it due to mechanical injury nor to the presence of other diseases such as root rot.

As an infectious disease, however, it may, like other diseases, be influenced in its distribution, quantity, and destructiveness by some or all of these factors. With so many varied factors concerned, it is impossible from our limited opportunity for investigation to determine which are influential at Soledad. Certain external conditions, however, noted during our stay there, seem to indicate that the progress of mosaic is comparatively unaffected by the following factors.

At Soledad, in the few tests which were made, the soil reaction was approximately the same (about neutral) in localities with the most mosaic as it was in those with the least. Moreover, in fields fertilized with press cake and in unfertilized fields, there was no significant difference in amount of mosaic that could be attributed to this cause. At Soledad also there was convincing evidence that mosaic was no more abundant or serious on cane injured by mechanical accident or by root rot or other diseases than on uninjured cane.

We are convinced from Mr. Grey's experiments and from our own field observations that mosaic plants may give rise to apparently healthy stalks, and hence in this sense by no means remain perpetually and completely diseased with mosaic. What factors influence this putting forth of apparently healthy shoots from diseased stools cannot be established until a careful quantitative record of the behavior of a large number of mosaic plants over a long period of time has been kept. This, therefore, is recommended as one of the pressing needs in mosaic investigation. Until then it cannot be stated with any certainty what causes this apparent recovery.

The amount and distribution of rainfall undoubtedly have an influence on the exposure of cane to risk of inoculation. The prevalence of *Aphis maidis* and of other possible carriers will vary in some measure with the succulence of the plants on which they feed. Nevertheless, it would be unwise to draw definite conclusions in regard to this relationship at present. Published tables of the total annual rainfall at a given station are of little value because of the essential importance of distribution throughout the year, and even the daily records of rainfall at particular points cannot be used for generalization because of the extraordinary variation in the daily record at places within a few hundred yards of each other.

4. Injuriousness of Mosaic

The mosaic disease of sugar cane has been considered by some writers to be very seriously destructive, and by others to be comparatively harmless. These writers have arrived at their several conclusions in two ways: First, by the general impression gained by their observation of large field areas; and second, by an accurate determination of the exact behavior, amount and nature of growth, and ultimate weight yield of mosaic-infected stools in comparison to healthy ones when grown under continual observation in test plots. This second method would seem to furnish the more reliable information even though derived from a relatively small number of individuals. The extensive literature already published on mosaic con-

tains but few articles based on such test plots. Edgerton and Brandes in the United States, Hansford in Jamaica, and Lyon and Kunkel in Hawaii are among the few investigators who have contributed exact information on the injuriousness of mosaic to cane. All of these men are agreed that cane mosaic results in loss of tonnage, but the amount of loss varies greatly — from a very low per cent in some cases to as much as forty per cent in others — depending upon the variety of cane and the conditions under which it was grown. And all of these investigators have been concerned with varieties other than Crystalina in other countries than Cuba.

Unfortunately, such detailed quantitative studies of loss from mosaic have been made in only the few cases mentioned. From the many other cane-growing countries in which mosaic is known, we have reports based on the impression which various investigators have gained from general observation over extensive field areas. These reports contain widely diverging opinions on the destructiveness of mosaic. To some extent these differences may be laid to the personal equation, as they are but carefully considered statements of opinion. In the main, however, such marked differences of opinion much more probably may be accounted for by some of the following possibilities.

1. It is possible that the effect of mosaic may vary in different parts of the world, in different localities in one district, and perhaps even in the same locality at different times in response to variations in the whole environmental complex of growing conditions. It is conceivable that the moisture, sunlight, temperature, soil, growing season, cultural methods, and so forth in such places as Porto Rico and Louisiana, for example, might result in widely differing losses even with the same variety of cane.

2. It is possible, also, that there may exist in the various sugar growing countries several strains of cane mosaic which possess a greater or less degree of virulence. Since such strains are known to exist in certain other pathogenic organisms, they have been suggested as a possibility in the case of cane mosaic.

Such an hypothesis must be proved, however, and its proof would depend on the hitherto unachieved feat of growing mosaic in artificial pure culture. The various supposed strains could then be isolated and tested under controlled conditions on some one variety of cane. Until it is possible to do this, however, it is unlikely that such an hypothesis will have any practical bearing on the mosaic problem.

3. Finally, it is now well established that the several types of cane grown in different parts of the world, vary markedly in their intolerance to mosaic — that is in their ability to support the disease without appreciable injury therefrom. Comparative studies have been made of the response to mosaic by a number of the commercially grown varieties of cane in Java, Hawaii, and Porto Rico. Except for that group of hard, thin canes such as Uba, Zwinga, etc., which so far as is known do not become infected with mosaic, the common varieties of cane, although they are all subject to mosaic, differ greatly in the amount of ill effect that they suffer.

It seems probable, therefore, that the differences of opinion as to the seriousness of mosaic in various cane growing countries may be accounted for largely by the amount of tolerance of the varieties of cane grown, and by the varying growing conditions in those countries.

Confronted, therefore, by such varied opinions emanating from other countries and concerned with other varieties of cane, it is not possible to say just how much of these reports on the injuriousness of mosaic apply to Cuba in general and to Soledad in particular. Our judgment as to the losses suffered in Soledad, therefore, is based on our examination of the fields in February, on the records of yield which have been kept over a long period, and on information gained from those who have been on the estate for many years.

When discussing the injury to cane by mosaic as shown in reduction of yield, it is necessary to consider both the degree of injury to individual plants and the total numbers of plants infected. Various combinations of these two phases may be concerned in the resulting loss of field tonnage. For example, in-

dividual plants might be but slightly injured by mosaic, but it might spread so rapidly that even this slight loss when affecting a large proportion of the field would reduce the tonnage materially. On the other hand, mosaic might injure individual plants so severely as to kill them in a very short time; but if no rapid spread had occurred, and a relatively small number of plants had died, the total loss would be negligible. If, however, mosaic were to injure individual plants severely, and also to spread rapidly over vast areas as well, the resulting loss would be enormous.

In considering the losses from mosaic at Soledad, let us first take up the matter of injury to the individual plant. Such injury might show itself in the specific destruction of tissue in the leaves and stem, or in the general reduction in vigor of the plant involving a decrease in the size or number of shoots, or a diminution of sugar content. At Soledad, as elsewhere, the obvious effect of mosaic on the leaves is the disarrangement of the quantity and distribution of the green color, so that instead of being uniformly dark green throughout, they show an irregular mottling of light and dark green areas. Obviously the presence of mosaic in the leaf has had some effect on the important chlorophyll bearing cells; yet in the case of the Crystalina cane which occupies practically the whole field acreage at Soledad, there is no destruction of these or of other leaf cells, no deformation, curling, wrinkling, or withering of the leaf as a whole, and no indication, in fact, that the leaf is seriously harmed. The leaves of a plant infected with mosaic continue to develop and apparently also to function in a normal manner. Analyses of the juice indicate that the production of carbohydrates is not diminished. It will take an extended investigation both of the chemistry of the green pigment and of the microscopy of the chloroplasts which bear it before one can decide with certainty just what occurs.

Interference with the chloroplasts in certain other genera of plants may result in widely different degrees of injury to the leaves. In the case of certain susceptible species of Solanums, mosaic practically destroys the leaves. In more resistant Sola-

nums, the leaves remain comparatively unaffected. Presumably a somewhat similar variation may occur in sugar cane. It is probable that many of the more tolerant varieties have such an excess of chlorophyll that in the brilliant sunlight of the tropics there may take place in spite of the mosaic an amount of photosynthetic activity quite sufficient for the needs of the plant.

At Soledad, also during the month of February a search was made in the fields for those injuries to the stem which have been described from other countries as the result of mosaic. Although these descriptions vary somewhat, they comprise in general two categories of injurious effects. One involves the distintegration of the stem tissue which breaks down in elongate streaks, and results in a grooving and furrowing of the rind, or even in the formation of lesions, cracks, and cankers. The other involves the checking or inhibiting of the growth of the internodes — both in length so that the plant becomes stunted and "telescoped," and in diameter so that the stem becomes unevenly bulged and constricted.

We saw no indication at Soledad of such seriously injurious effects as these, or of any other decidedly destructive effect which could be attributed to mosaic alone. Dwarfing of the plant as a result of root rot was seen, as was also injury to the stem resulting from root rot, red rot, and rind disease; and occasionally mechanical injury and even sun-scorching were found to produce injuries to the rind that approximated those ascribed to mosaic. It is possible that at Soledad under circumstances extremely unfavorable for cane growth the presence of mosaic in the plant from its earliest development would be the deciding factor that would result in keeping the plant dwarfed, but under the varied conditions found in the field last February, no such injury had occurred; and the differences in size and vigor between healthy and mosaic plants was too slight to indicate any correlation.

It is possible, also, that old cane stalks which had lasted over from the previous crop season beyond the proper time for cutting might develop, as a result of long-standing, mosaic infec-

tion, lesions, cankers, or other serious stem injuries. No such old canes persisting from the previous crop were seen at Soledad; but in other representative plants of all ages, from those recently planted to those ripe for cutting, the destructive cankers so frequently described elsewhere were not found.

It is hard to reconcile this with the reports from other countries. The inference seems to be that Crystalina may be a variety very tolerant to mosaic — far more tolerant, for example, than Otaheite, large areas of which have been reported killed by mosaic in Porto Rico. It is of interest to note that Bruner in his most recent paper on mosaic concludes from observations in other parts of Cuba that Crystalina shows some tolerance to mosaic and only rarely develops cankers.

It is also of interest that R. A. Veve of Porto Rico when reporting on the situation at Soledad after his visit there some months ago, said that shrinking of the internodes was noticeable only on a small scale and that splitting or cankering of the internodes was not found in a single case. This lack of stem injury he attributes to the variety, Crystalina, a variety which he says "only in extreme, advanced cases will show the cracking of the nodes, and in good lands where the cane has a vigorous growth this symptom is very seldom found." Veve states further that the cracking "always occurs in old lands in the third or fourth generation." Whether he means by generation a ratoon cutting or a new planting is not clear, but in any case, we did not find the cracking or splitting of the stems either in heavily mosaiced fields that had been cut for six or eight ratoon crops or in fields that had been replanted to cane repeatedly.

Moreover, in Soledad, not only is the structure of the stalk uninjured by mosaic as far as we could determine, but also the yield in sugar per pound of stalk is apparently unimpaired. Analyses made from time to time by the chemists at the mill show clearly that in mosaic-infected Crystalina cane developing under ordinary field conditions no appreciable reduction either in sugar content or in purity had taken place.

The second important point which must be emphasized when considering losses from mosaic is the rapidity of spread of

infection, and the number of diseased plants resulting therefrom. The relatively short period of time at our disposal for personal observation necessarily gave us no accurate and significant first hand information. Knowledge of this very important phase of the problem can be secured only by a careful entomological study of the rôle played by insect carriers at Soledad, and the conditions favoring secondary spread by means of them.

When considering the whole question of loss of tonnage due to mosaic at Soledad, we were forced to depend on the field evidence available at one short period of the year, and upon the general mill records of tonnage. Such a basis for judgment is not satisfactory from the quantitative point of view. To ascertain accurately the tonnage losses actually being borne at Soledad, careful records must be kept on a large scale of the development, growth, and tonnage yields in plants of healthy and mosaic cane — the time of infection of each individual being noted, and a history of the progress of each stool being kept — from seed to harvest and through a number of ratoon crops.

Such an experiment carried out by Lyon in Hawaii on Lahaina cane over a period of two years showed clearly that while mosaic cane of that variety did not suffer loss in sugar content or purity, it did show a loss of as much as forty per cent in tonnage. By following the yield of twenty-three varieties in a similar but less critically conducted experiment, Lyon concluded that not one of them — not even the more tolerant — could support mosaic for several years without some reduction in tonnage.

More recently Kunkel, in the most careful and comprehensive experiments yet made on this point, has shown that all the seven important commercial varieties of cane which he grew in four quite different districts in the Hawaiian Islands, regularly suffered a reduction in tonnage — slight in some cases and severe in others.

Unfortunately, no such experiments have been made on Crystalina in Cuba, and we are forced to base our conclusions on our personal field observations of last February, and upon

the general records kept by the mill. The records of average tonnage per acre at Soledad during the years since mosaic was first noticed there show some fluctuations, but no evidence of a steady decrease which can be attributed to the disease; and from our field observations, we can only report that the diseased canes of Crystalina at Soledad appeared to be growing as vigorously as canes showing no disease. We are inclined to believe that this apparent difference in the effect of mosaic on Crystalina as briefly examined at Soledad, when compared to the consistently much more injurious effect as ascertained for other varieties by Lyon and Kunkel in Hawaii, and compared to the devastation of the Otaheite variety in Porto Rico, indicates a markedly greater tolerance in the Cuban cane.

5. Potentialities of Mosaic

Two phases of the mosaic problem that are of the utmost importance to Soledad are: — First, is mosaic at the present time increasing in extent, amount, and injuriousness on this estate? and second, will mosaic in the future become devastatingly destructive? Towards answering these questions there is some significant evidence.

It is possible that mosaic may be increasing in extent at Soledad. From our observations, however, and from those of Mr. Hughes, Mr. Leonard, and others, we judge that it occurs already in all parts of the estate. Indeed, what evidence there is available suggests strongly that it is already distributed throughout the whole of the Island of Cuba. Whether mosaic is increasing in amount — the amount of infection per acre — and in destructiveness through injury to growth or diminution of sugar production, can only be determined with certainty by a comparison of accurate field records for the last five or ten years. Exact records of the amount of mosaic — the number of mosaic plants per acre — unfortunately have not been kept at Soledad during past years. Some qualitative evidence, however, may be adduced from the fact that Mr. Hughes, Mr. Leonard, Mr. Grey, and others who have been observing mosaic since it gained such notoriety in 1919 are agreed that, while

they consider that the amount of mosaic has varied considerably during these years, it has not on the whole shown an appreciable increase.

Moreover, a limited amount of quantitative evidence can be derived from the information available on a few fields. One of these, Field 82 at La Vega, is of particular interest. This field was reported by Mr. Grey and Mr. Anderson to have had a heavy percentage of mosaic in 1920 although our count made in February 1924 showed only 14.6 per cent of mosaic in over one thousand stools carefully examined. It would appear that the per cent of recognizable mosaic in this field is now less than it was four years ago, but unfortunately there are no records available of the actual counts which were made in 1920. Whether the percentage was lowered because many of the stools with mosaic have since died out, could only be determined if we had records following the history of each clump during these four years. It can be stated definitely, however, that the existing vacancies found in the rows last February do not account for more than fifteen per cent of the decrease in infection; and it is probable that this reduction from the heavy infection of 1920 to the present 14.6 per cent may be due to the recovery of some stools in the past four years. It must be remembered, however, that this comparison takes no account of the stools which have died or been replanted, or of the occurrence of secondary infection by insects during that time. The field is interesting only as it offers a rough comparison of the gross amount of mosaic in it after a four year interval.

An instance such as this shows clearly the need of a quantitative study of the increase or decrease of mosaic in the field, and it is encouraging to know that investigations of this kind will be undertaken under the direction of the Cuba Sugar Club in the near future.

Whether mosaic in the future will become devastatingly destructive at Soledad is a difficult question; for, while we are convinced that its effect on the cane there at the present time is not disastrously injurious, still we realize the difficulties of predicting accurately its future behavior from its present condi-

tion. In our opinion there are two possibilities as to the future trend of mosaic on this estate.

First, it is possible that mosaic may go on as at present for several, perhaps for many years, and then suddenly under a combination of conditions especially favorable for its development, it may assume the intensity of a severe epidemic, and become exceedingly destructive. If mosaic of sugar cane only recently has been introduced into Cuba, it might be expected to act in this way; but if it has been present here for even as short a time as ten years, it seems probable that in some season during that period conditions already must have been sufficiently favorable to induce a devastating epidemic if such an epidemic were going to occur.

Opinions differ as to how long mosaic has been present in Cuba as a whole, some maintaining that mosaic is of long standing in the Island, others that it has been introduced there only within the last few years. However, concerning the length of time that mosaic has been present at Soledad and in the vicinity, there is some definite evidence. Mr. Grey, who has been observing the Soledad fields for many years, is confident that mosaic has existed there for at least eighteen years. Brandes, after reporting finding mosaic at three different points in Cuba in 1919, added "At Cienfuegos" (the city which the Soledad property adjoins) "it has been present for nearly twenty years." Also Mr. L. D. Larsen of Hawaii, during a short visit to Cuba in 1915, reported the occurrence of mosaic of sugar cane "in a central near Cienfuegos" — Soledad. (Bruner, 1923.)

It seems very doubtful that mosaic, if it were going to develop into a destructive epidemic at Soledad, would not have done so in the period of years since it was first recognized with certainty there. Indeed, in the history of plant pathology, it has been noticeable that introduced diseases, such as the grapevine mildew in France, and the chestnut blight in America, which do thus become devastatingly destructive, usually develop with noticeably increasing virulence in a relatively short time after their introduction.

Second, it is possible that mosaic may continue indefinitely at Soledad to behave as it does at present, varying in amount according to conditions in different localities, and without developing more virulence than it has shown already.

No one can predict with certainty which of these two possibilities will result, but in the case of Soledad, we believe that mosaic will continue to behave approximately as it does now. In our opinion, the evidence is strong that the mosaic disease long has been established there; and that through continuous association Crystalina cane, the commonly grown variety, and the mosaic infecting it have reached a state of balance with resulting toleration on the part of the cane and relative harmlessness on the part of the mosaic. Perhaps also, there are operative other factors such as those embodied in Brandes' suggestion in 1919 that while mosaic has been present at Cienfuegos for nearly twenty years, "it has spread very little" . . . . "as a result of discarding diseased plants in the seedling and propagating fields because of their unthrifty appearance, and perhaps partly owing to the fact that a proper agent of transmission was not present or at least not abundant in this region."

The foregoing points seem in our opinion to indicate strongly that the mosaic situation at Soledad will continue with very little change; but it should be noted that the present balance of the situation depends on the factors now operating, and might be disturbed by introducing some new factor. For example, the sudden extensive growing of varieties much more susceptible than Crystalina might bring about a sudden increase in the destructiveness of mosaic; the use of new forage grasses such as the elephant grass (*Pennisetum purpureum*), which is becoming increasingly popular, might offer more favorable cover for the propagation of insect disseminators; or changes in agricultural practice might offer unexpected aid to the disease by driving the insect carriers into the cane. A balance such as that of the present which might be thus upset should not be relied upon implicitly as permanent without further investigation. There are too many unknown factors involved, and too

many phases of the nature, spread, and virulence of the disease that are obscure. It is highly inadvisable, therefore, to relax the careful seed selection and other restrictive measures which have contributed apparently to maintaining this balance at Soledad in the past.

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BIBLIOGRAPHY

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No attempt has been made to include the numerous articles, editorials, and discussions on cane mosaic which have appeared in the various sugar journals; as these articles have been found to be chiefly reviews, résumés, or rewritings of original papers published in the more technical bulletins and referred to in their original form in the bibliography. We include, therefore, very few references to such sugar journals as "Sugar," "Facts about Sugar," "The International Sugar Journal," "The Sugar Central and Planters News," and the "Louisiana Planter."

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EXPLANATION OF PLATES

All phases of the symptoms and effects of mosaic of sugar cane have been illustrated so well and in such detail by the several investigators mentioned in this report that little remains to be added. No new illustrations, therefore, are presented here as the result of our month's work in Soledad. It has seemed helpful to the purposes of this report, however, to bring together certain of the excellent plates published by others so that one might compare the symptoms of mosaic — an infectious chlorosis — with those of certain non-infectious, hereditary chloroses which resemble it sufficiently to cause occasional confusion.

PLATE I

This plate was taken from one prepared by W. R. Potter at the Hawaiian Sugar Planters' Experiment Station under the direction of H. L. Lyon and published by him in 1921. It shows very accurately the characteristic types of mottling resulting from mosaic infection in the leaves of (1) Striped Tip, (2) Hawaii No. 355, (3) Hawaii No. 27, (4) Hawaii No. 207. The mottling of mosaic leaves of Crystalina cane at Soledad was in general similar to that shown in Striped Tip in Figure 1, although at times the pale green areas were more extensive. In no cases, however, were spots of dead tissue such as are shown in the leaves of Hawaii No. 27 and Hawaii No. 207, in Figures 3 and 4, found in leaves of Crystalina at Soledad as the result of mosaic.

1
3
2
4

PLATE II

This plate, taken from an excellent half-tone published in 1921 by H. L. Lyon in his bulletin on "Three Major Cane Diseases," shows the effect of mosaic on the leaves of (*a*) Striped Tip, (*b*) Lahaina, and (*c*) Hawaii No. 109. It is in part illustrative of the effect of mosaic on Crystalina also, as the mottling in Lahaina and Hawaii No. 109, Figures *b* and *c*, is very similar to that generally seen in the fields at Soledad

a
b
c

PLATE III

This plate is taken from one painted by W. R. Potter and published by L. O. Kunkel in 1921 as Figure 4 in Plate IV of his valuable bulletin on mosaic of maize or Indian corn. A portion of a leaf of field corn, United States Selection No. 120, with the typical mosaic mottling is shown. As the mosaic of maize has been shown by E. R. Brandes to be the same as the mosaic of sugar cane, this plate furnishes an interesting comparison to the preceding plates of cane leaves.

PLATE IV

Finely striped leaf — an inherited chlorophyll abnormality of maize. Photo. by R. A. Emerson. This plate, together with Plates V, VI, VII, and VIII which follow, illustrate leaves with inherited chlorophyll abnormalities of maize, and present an interesting comparison to the mosaic-mottled leaves of maize and sugar cane shown in the preceding plates. This comparison indicates clearly that the leaf markings of inherited chloroses usually show a more or less regular pattern; while the leaf markings of mosaic — an infectious chlorosis — show an irregular mottling.

Also on comparing these plates, it is obvious that the amount of chlorophyll in the leaves may be reduced even more in the case of plants with such inherited abnormalities than in the case of plants with mosaic. Even this considerable reduction, however, does not necessarily affect the health of the plants adversely; and most of these types of maize yield crops fully as large as those produced by the normal green types from which they have been derived. Indeed, Mr. G. N. Collins of the United States Department of Agriculture has informed us that in some of his experiments the types with hereditary chlorophyll abnormalities have, when planted in the South, given even better yields than the normal green types from which the abnormal have sprung. This seems to us to indicate that one cannot assume *a priori* that any agency which reduces the amount of chlorophyll in the plant necessarily affects the plant adversely.

PLATE V

Above: Japonica variety of maize.

Below: Striped Leaf, a variety of maize in which the abnormality is inherited as a maternal character only.

After E. G. Anderson.

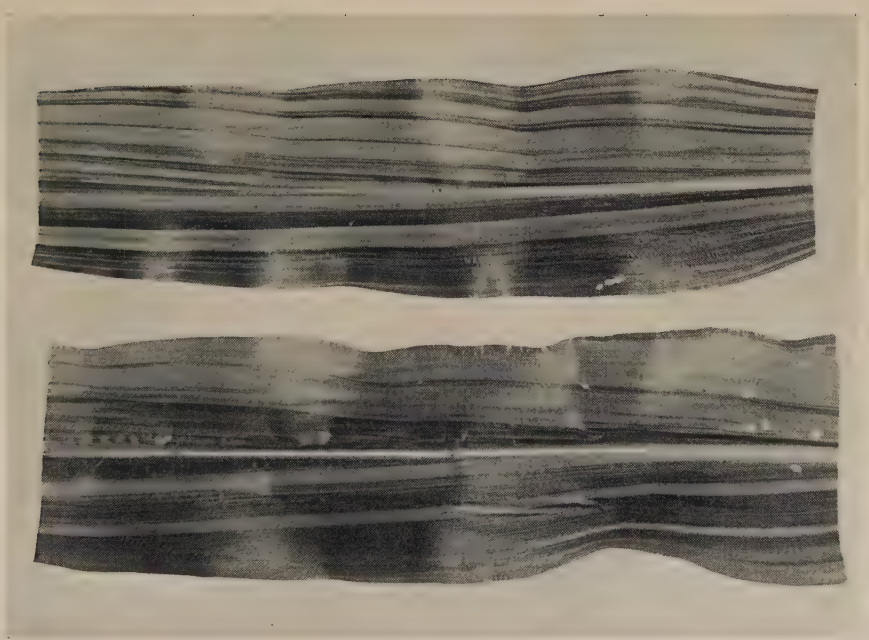


PLATE VI

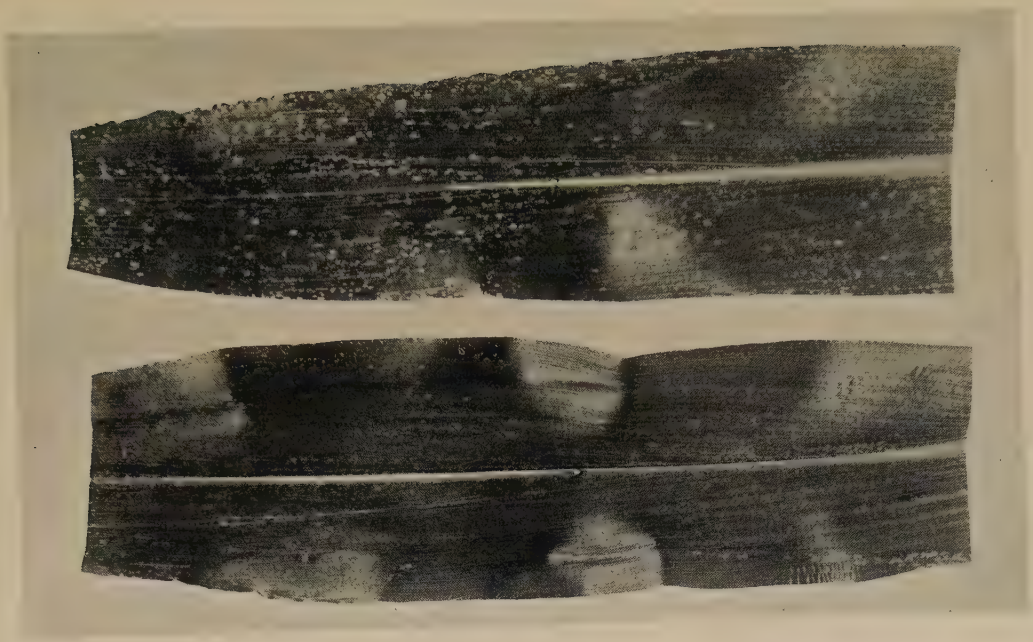
Inherited chlorophyll abnormalities of maize.
After W. H. Eyster.

PLATE VII

Inherited chlorophyll abnormalities of maize.
After W. H. Eyster.

PLATE VIII

Inherited chlorophyll abnormalities of maize.
After W. H. Eyster.

PLATE IX

Above: Dotted leaf. After R. A. Emerson.
Below: Blotched leaf. After R. A. Emerson.
These abnormalities of maize are inherited, but it has not been determined whether these, like the chlorophyll abnormalities shown in the preceding plates, are inherited as such or whether there is transmitted a susceptibility to ubiquitous organisms which attack the leaves and cause destruction of the chloroplasts. In any case, they present an interesting comparison to the pattern of inherited abnormalities, the mottling of mosaic, and the leaf injuries sometimes described and illustrated as the result of mosaic.